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Performance comparison of direct expansion solar-assisted heat pump and conventional air source heat pump for domestic hot water

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Abstract

In this work, performances of conventional air source heat pump water heater (ASHPWH) and direct expansion solar-assisted heat pump water heater (DX-SAHPWH) under various operating conditions are analyzed to make comparison between the two systems. The DX-SAHPWH system in this study uses a plate type roll-bond solar collector with optimized flow channel as the evaporator, which can take both solar energy and ambient air as the heat source. Performances of both systems are investigated experimentally and numerically. The influences of operating conditions (air temperature, water temperature, solar radiation intensity, et al) are analyzed, and performance comparison under various operating conditions is made between the two systems. Results show that, in clear day conditions, the COP of DX-SAHPWH is obviously higher that of ASHPWH because the solar energy can improve the evaporating temperature of the heat pump obviously; in overcast day conditions (without frost formation), COP of both systems are almost the same; and in night conditions, especially in clear night conditions, the DX-SAHPWH shows poor performance because of the poor convectional heat exchanging performance of the solar collector/evaporator and the radiative heat loss to the night sky. And annual performance analysis shows that the average COP of the DX-SAHPWH system is remarkably higher than the conventional ASHPWH system, especially in winter season.

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Keywords: solar; heat pump; water heating; COP

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1. Introduction

Nowadays, the building sector accounts globally for about 40% of the society energy consumption. And domestic hot water, after air conditioning, has become the second largest contributor to residential building energy consumption. So, for the last decades of years, as energy shortage draws attention of the whole world, building energy conservation has become a focus of researchers. Consequently, study on high-efficiency domestic hot water also becomes an important topic. New systems as well as new energy sources are proposed to take place of the conventional electrical or fossil fuel water heater to improve energy efficiency and reduce energy consumption. Among those water heating systems, air source heat pump water heater is one of the most promising technologies.

The air source heat pump water heater (ASHPWH), operating following a simple mechanical refrigeration cycle, takes the ambient air as heat source. Since the ambient air can provide heat stably, the heat pump system can operate reliably. Compared to electric resistance water heater, the electric-driven ASHPWH can save power consumption by 40%-60% [1]. While since the performance of ASHPWH is significantly influenced by the ambient temperature, poor performance caused by low ambient temperature has become the main obstacle to the application of ASHPWH in high latitudes.

Direct expansion solar-assisted heat pump water heater (DX-SAHPWH), first proposed by Sporn and Ambrose [2], is the combination of solar heating and heat pump technology. As mentioned above, the ASHPWH shows good operating stability but poor performance under low temperature situation. In contrast, solar water heating is totally free, though the supply of energy is unstable. The DX-SAHPWH combines the advantages and overcomes the disadvantages of both ASHPWH and solar water heating system [3]. In a DX-SAHP system, the solar collector works as the evaporator of the heat pump system simultaneously, and solar is taken directly as the heat source for the heat pump system to improve operating performance [5-11]. When a bare solar collector is used, the collector/evaporator can abstract heat from both solar radiation and ambient air, thus the combined system can operate in all weathers conditions all day [4].

In this work, performances of ASHPWH and DX-SAHPWH under various operating conditions will be investigated experimentally and numerically to make comparison between the two systems. Results show that, in clear day conditions, the COP of DX-SAHPWH is obviously higher that of ASHPWH; in overcast day conditions, COP of both systems are almost the same; and in night conditions, especially with low ambient temperature, the DX-SAHPWH shows poor performance.

2. system schematic and operating principles

2.1. system schematics and experimental set up

Fig.1 shows the structure of typical ASHPWH and DX-SAHPWH systems. Both systems operate according to a simple mechanical refrigeration cycle. The only difference is that the DX-SAHP system uses a solar collector to replace the fan-coil unit evaporator, thus solar energy could be exploited as the heat source of the heat pump. In clear day conditions, the DX-SAHPWH will show better performance because the solar radiation increases evaporating temperature of the system [2-4].

Plate-type solar collector with or without glass cover can both be used as the collector/evaporator of the DX-SAHPWH system. In clear day conditions, the glazed collector/evaporator performs higher heat collecting efficiency and lower heat loss. While when the solar radiation cannot supply enough heat for the evaporator, the glass cover will stop the collector/evaporator from extracting heat from the ambient air, unless an extra fan is used, which will increase the structure complexity and initial cost of the collector. In comparison, a bare collector/evaporator, with simple structure and low cost, can exploit heat from both solar and air easily. And operating at a temperature lower than the ambient most time, heat loss rate of a bare plate collector/evaporator is actually low [5]. Thus, in this work, a bare plate roll-bond solar collector made of aluminum is used as the evaporator of the DX-SAHPWH system. And the flow channel of the roll-bond panel has been optimized to enhance the performance of the collector/evaporator [4, 6]. Parameters of the experimental set up for this work is listed in table.1.